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# Analysis of DC Electric springs in the micro grid system consisting of fluctuating Energy sources

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## Abstract

This paper deals with the reduction of power drawn from the supply system during generation un-certainties in D.C Micro grids using D.C Electric springs. In this work supply system is modeled using a fluctuating power source and a battery i.e. during generation uncertainties the system runs on battery support. A small micro grid system which has a critical load and non-critical load has been taken for the study and the simulations are done in MATLAB. The objective of the proposed work is to conserve power by making the non-critical loads draw less power during generation uncertainties which in turn relives the battery and renewable generator to the possible extent. D.C Electric springs are extension to A.C Electric springs used in A.C systems which make the non-critical loads draw less power by adjusting the voltage supplied to them. The D.C Electric spring presented in this work is different from the existing technologies present in the literature in terms of the circuitry used and its interpretation with mechanical spring.

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*Keywords:* D.C Electric spring;Noncritical load; D.C micro grid; Supply system; Generation uncertainties

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## 1. Introduction:

D.C micro grids in the electricity distribution level especially for domestic and commercial applications are gaining momentum [1]. D.C power is more attractive because the losses in the D.C system are certainly low due to the absence of reactive power and also because many of the domestic equipment work on D.C supply [2]. Along with growing interest in the D.C micro grid system there is an increasing trend in connecting small and micro generation sources to the micro grid [3]. Presence of fluctuating energy sources in the micro grid causes generation intermittence which may lead to instability in the micro grid system [4]. Reliable supply of power in the complex grid environments can be achieved by effectively handling renewables, demand response and storage [5]. Making the transmission grid smart by designing smart transmission networks, smart control centres and smart substations reliability in power supplied increases [6]. In order to take care of the generation uncertainties in the D.C micro grid systems i.e. to match the demand and supply gap traditional methods like the full or partial load shedding can be employed. In the literature there is also one other technique to manage the demand supply gap by shifting the non-critical/curtailable loads to the off peak times and is known as Demand side management (DSM). The article [7] presents an optimal methodology to reduce the demand supply gap by optimally scheduling the controllable loads in a D.C smart home system. The authors in [7] considered heat pump and battery as controllable loads and scheduled the smart home system using tabu search optimization algorithm. Taking water heater as controllable loads the authors in [8] presented a novel technique to schedule the loads based on the cost settings made by the house/building owners in order to make load management cost effective as per the requirement of the consumers which is again an optimal way of scheduling the loads. Apart from DSM using batteries in conjunction with the fluctuating renewable energy sources will also help to reduce the demand supply gap i.e. whenever there is sufficient power generation in the grid the battery will charge itself and during generation deficits the battery supports the system by providing the required power. In A.C systems a new technology by name Electric springs has been proposed [9] which makes the non-critical loads drawn lesser power (instead of curtailing them completely) during generation uncertainties and make the battery storage requirement to be low which means that the power drawn from the supply system (battery and generator) gets low [10]. Different applications and uses of A.C Electric spring for different problems were presented in the literature. In [11] the application of A.C Electric spring in providing reactive power support and voltage regulation has been projected and the dynamic control strategy for voltage and frequency control at power system level has been reported in [12]. In providing reactive power support to the system the performance of STATCOM is compared with A.C Electric spring in [13] and it has been found out that spring is more effective in providing reactive support than the STATCOM and the effectiveness of spring in mitigating the voltage and frequency fluctuations is demonstrated in [14] which is also quite encouraging. Further it has been presented in [15] that A.C spring is capable of reducing the power imbalance in three phase power systems to considerable level. Inspired from the concept of A.C Electric Spring to achieve the objective as did in the A.C system the concept of D.C Electric spring is proposed in this paper as an extension of A.C Electric springs to reduce the power drawn from the supply system during uncertainties in power generation.

A D.C Electric spring in a different perspective and different application has been presented in the literature [16]. In [16] the authors presented a different inference for Mechanical and Electric spring and also designed an Electric spring with a different circuitry and used for power quality applications to mitigate voltage sags and swells whereas the DC Electric spring(E.S(D.C)) presented in this work is different in terms of circuit design, application and its interpretation with Mechanical spring.

## 2. Methodology and Problem formulation:

To realize the concept of D.C Electric spring a micro grid which consists of loads and the supply system is considered as shown in Fig.1. It consists of a fluctuating A.C source connected to an AC/DC converter which in turn feeds the D.C Critical and Non-critical loads. The micro grid system also consists of a battery which supports the loads during uncertainties in the AC source. Hence the supply system (Complete setup of source and the storage system) is expected to supply required power to critical and noncritical loads even during uncertainties in the source.

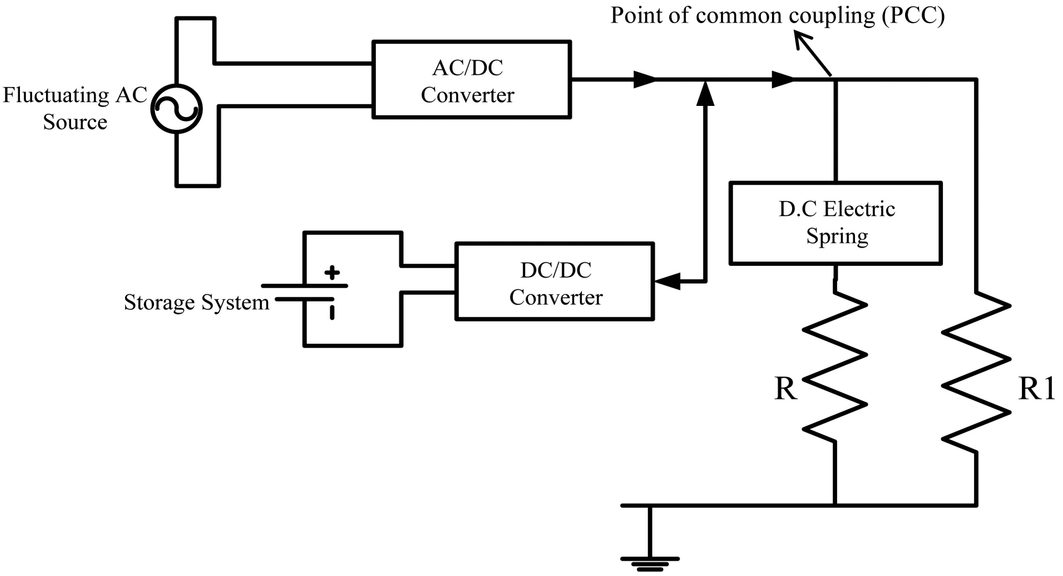

Fig. 1 Micro grid system considered for the study

In general during un-certainties in generation to reduce the burden on the supply system especially the non-critical loads like the waters heaters will be cut off and will be switched 'ON' whenever there is sufficiency in generation because water heaters can heat up water and the heat can be retained for longer times [17]. In this paper to conserve power during deficits, the power drawn by the non-critical load is controlled by regulating the voltage applied to the non-critical load because loads like water heaters can sometimes(during generation uncertainties) be operated at larger voltage tolerance values (Approximately 20 % from their rated value). Whereas critical loads are those types of loads which are not curtailable and also it is essential to maintain voltage at specified tolerance levels. The other examples of non-critical loads can be lighting systems used in parking lots, stairways where little more change in illumination level is acceptable.

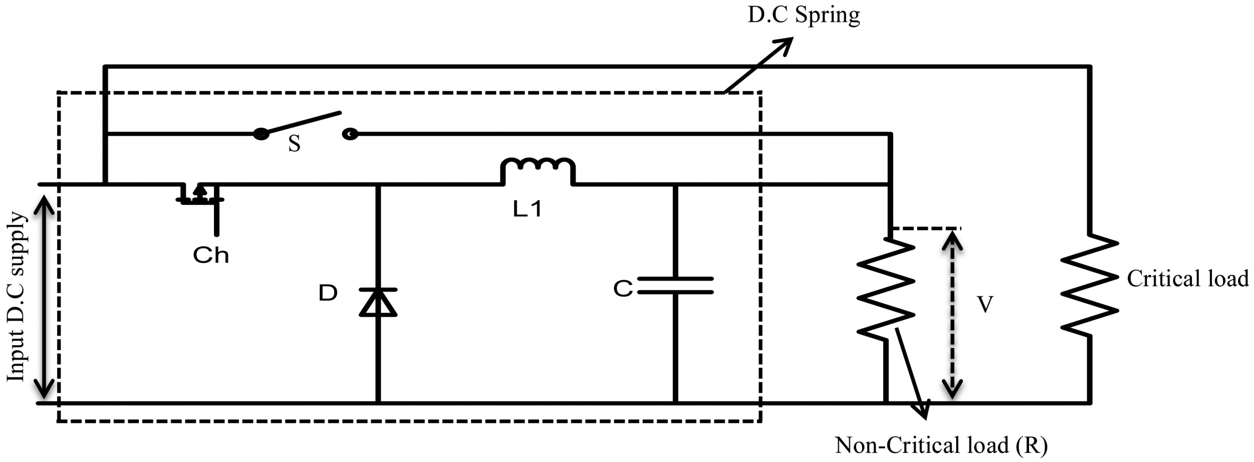

Fig. 2 Connection diagram of D.C Electric spring

Fig.2 shows the connection diagram of D.C Electric spring which is connected along with the non-critical load. The word D.C Electric spring is coined by taking inspiration from the mechanical spring. An ideal mechanical spring when stressed with certain force from one direction it transfers the same to the other side of it. This transfer of force from one side of the Mechanical spring to the other side is dependent on the applied force i.e. lesser the force applied lesser will be the transfer and higher the applied force higher will be the transfer. In the same way D.C Electric spring works with reference to the source voltage i.e. if the source voltage is sufficient enough then the complete voltage will be applied to the non-critical load like when sufficient force is applied to the mechanical spring it transfers it completely to the other side here electrically that is achieved by closing Switch (S) and whenever there is deficiency in the renewable generator voltage (not the voltage by considering battery support) it means that there is no enough force on the spring which will lead to lesser transfer of force to the other side. This is achieved in the Electric spring by opening 'S' and operating the Chopper (Ch) by which lesser voltage will be supplied to the non-critical load. In this away as the complete circuit is analogous to mechanical spring it is called Electric spring and as it used in D.C circuitry it is called D.C Electric spring.

Now coming to the actual operation of D.C Electric spring, during uncertainties in generation the switch(S) is open and the chopper (Ch) is supplied with the Controlled PWM pulses in such a way that the average value of voltage applied to the non-critical will be reduced to the certain tolerable value which is lesser than the rated value and now whenever there is sufficient generation the switch(S) is closed which means the entire chopper circuitry is bypassed and full rated value of voltage will be applied across non-critical load. The Inductor (L1) & capacitor(C) present in Fig. 2 are used to filter out the ripples in the D.C component supplied to the non-critical load and Diode (D) is used for freewheeling action.

The relation between the voltage applied to the noncritical load and the power drawn from the supply system is as explained below.

$$P = P_C + P_{NC} \tag{1}$$

$$P_{NC} = \frac{V^2}{R} \tag{2}$$

$$\mathrm{P} = \mathrm{P_s} + \mathrm{P_b} \tag{3}$$

Where P is the total power drawn by the critical and noncritical load from the supply system (Source and Battery), $P_c$ is the power drawn by the critical load which is always constant because the voltage applied to it is also almost constant and $P_{NC}$ is the power drawn by the noncritical load and it can be written as shown in Eq. 2, $P_s$ is the total power supplied by the source and $P_b$ is the power supplied by the battery. Hence the total power supplied by the supply system can be related using Eq. 3

Now considering a two folded objective of minimizing the power drawn from the supply system and battery the Eq. 1 can be written as follows

Minimization of power drawn from the supply system

$$\text{Min. } \mathrm{P} = \mathrm{P_c} + \mathrm{P_{NC}} \tag{4}$$

Minimization of power drawn from the battery storage system

$$\text{Min. } \mathrm{P_b} = \mathrm{P_s} - (\mathrm{P_c} + \mathrm{P_{NC}}) \tag{5}$$

In order to achieve the afore said objective stated in Eq. 4 & Eq. 5 the only option available is by reducing the power drawn by the non-critical load using Electric spring. From Eq. 2 it can be noticed that if the voltage applied to the non-critical load is reduced to a certain extent there will be reduction in the total power drawn from the supply system which in turn relives the battery also from supplying more power to the loads during generation uncertainties and as a result by using smart techniques like the D.C Electric spring the battery storage requirement in the future D.C micro grids will get low and hence low rated batteries can be used which again will reduce the capital and maintenance costs. So looking at the upcoming results it is also clear that not only battery but also the renewable generator is relieved to a certain extent during generation intermittence.

### *2.1 Control Strategy adopted for operation of battery and D.C spring:*

The battery as well as the spring will be operating only when the output voltage of the source falls below the normal rated value of 220 volt. The control signals for the battery are generated i.e. the DC/DC converter shown in the Fig. 1 will be triggered which regulates the voltage that has to be supplied by the battery. The generation of control pulses is as shown in Fig. 3

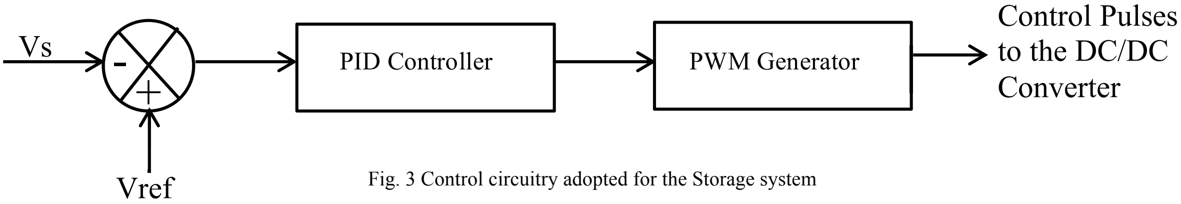

Fig. 3 Control circuitry adopted for the Storage system

Fig. 3 shows the control strategy adopted for the Battery storage system where Vs is the voltage supplied by the renewable generator and Vref is the reference value of the voltage which will be set to the actual rated value of the micro grid system. Now whenever there is change in voltage supplied by the renewable generator there will be error signal generated and it is processed by the PID controller and based on the requirement PWM generator generates pulses which feed the DC/DC converter and hence the battery is allowed to discharge which means the system runs on battery support.

Similarly control pulses are generated for the operation of D.C Electric spring and the control strategy is not very different from that one of the battery. By comparing the voltage supplied by the renewable generator and the rated value of the system voltage an error signal would be generated which will open the switch(S) in the spring circuitry and allows the power flow through the Chopper (Ch). Now whenever S is open the Chopper is gated using PWM pulses and only 180 volt is allowed to appear across the non-critical load which will lead to reduction in power drawn from the supply system during generation uncertainties.

## **3. Simulation results and discussions:**

The D.C micro grid system shown in Fig.1 is considered for the study and is designed in MATLAB which consists of a Fluctuating power source and converter to convert the generated A.C power to D.C and to feed the D.C loads. The ratings of the micro grid system are obtained from [9]. Although the systems considered for the study in [9] is an A.C system the same rating of the loads, source and the battery are taken here for the study of a D.C micro grid.

Fig. 4 shows the simulation diagram which is built in MATLAB. It consists of a Fluctuating power source which gives different D.C output voltages at different instants of time and the system ratings are as indicated in Table 1.

Table 1 Details of the D.C Micro grid system

| Nominal system voltage(Average value) | Resistance of non-critical load | Resistance of critical load | Battery capacity | |
|---|---|---|---|---|
| | | | Output DC voltage | Ah Rating |
| 220 volt | 27.5 Ω | 31 Ω | 208 V | 45 |

The battery storage block in the Fig. 4 actuates only when the voltage supplied by the source is lesser than the stipulated value. Initially the battery is considered to be fully charged and the rating of the battery considered shall not be considered as the optimum size. The simulations are done for 1800 second i.e. for half an hour time for preprogramed fluctuations in the output voltage and the variation of the source voltage is as shown in the Fig. 5

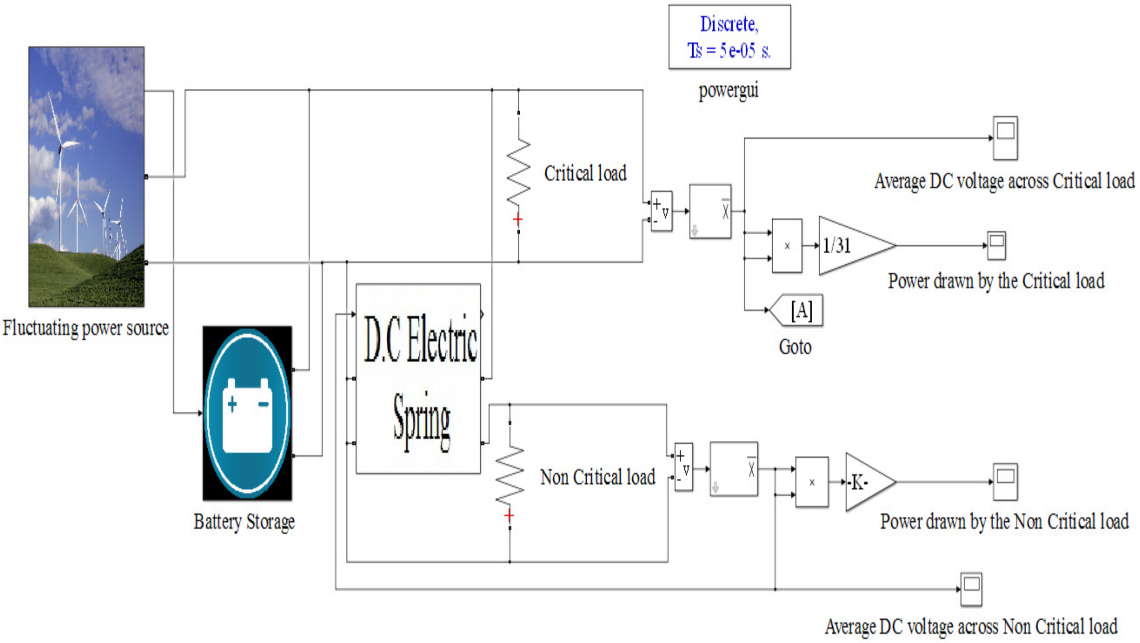

Fig. 4 Simulation diagram of the considered D.C Micro grid system

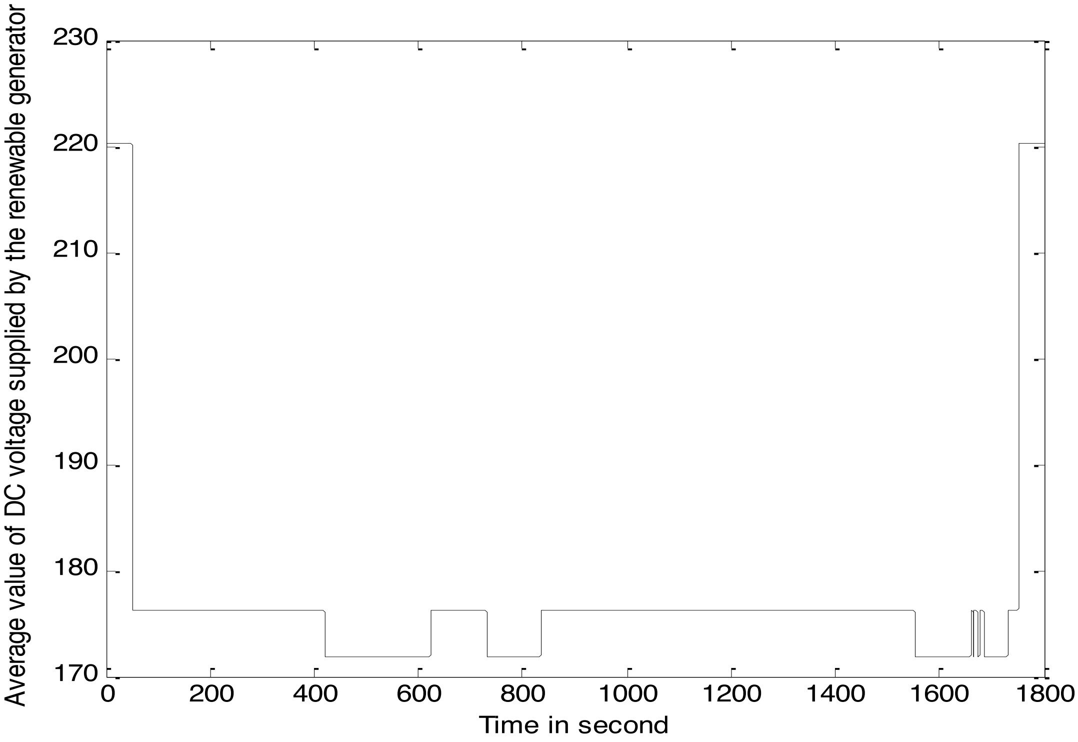

Fig. 5 Variations in the output voltage of the source considered for the study

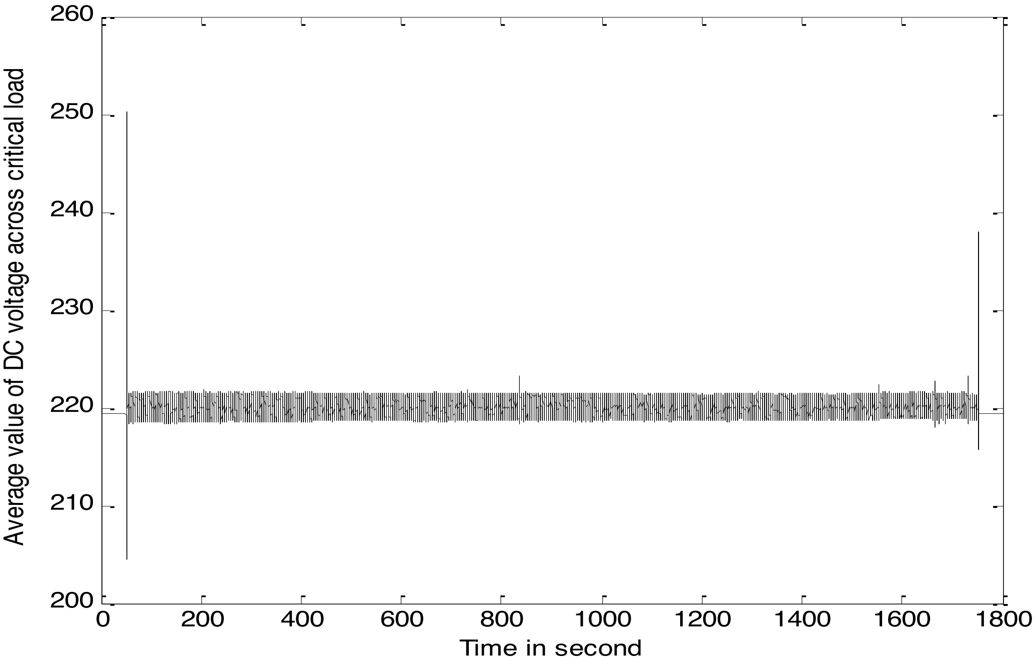

Fig. 6 Average value of Voltage across the Critical load

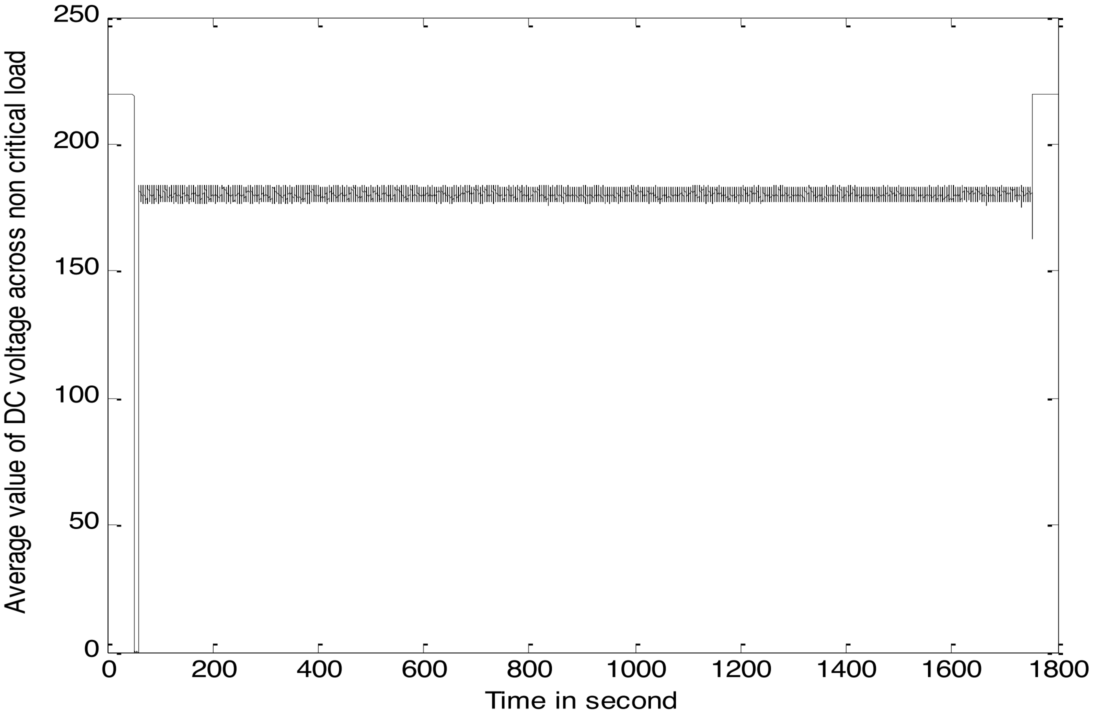

Fig. 7 Average value of D.C voltage across the non-critical load

Fig. 5 shows the variations in the source output voltage where the source voltage is maintained at rated value for the initial period of 50 second and after 1750 second which means that battery has to support the system from 50th second to 1750th second and also the electric spring has to operate to suppress a reasonable voltage across the non-critical load.

Here in this work during battery support the non-critical load is made to operate at a tolerance level of 20 % from its rated value which will result in saving the power drawn from the battery as well as the source during uncertainties in the renewable generator. During battery support i.e. after 50th second the voltage across the critical load is maintained at specified tolerance level and the voltage across the non-critical load is allowed to fall to 180 volt by the action of the spring as shown in Fig. 6 & Fig. 7.

From Fig. 6 & Fig. 7 it can be established that in steady state the voltage across the critical load is maintained at specified tolerance value and also the voltage across the non-critical load is maintained at a higher tolerance value in steady state due to the operation of spring and hence the power drawn by the critical & non-critical loads will follow the same and is as shown in Fig. 8 & Fig. 9.

Fig. 8 shows the average power drawn by the Critical load during uncertainties in generation as well as during normal operating condition where the power drawn by the critical load is almost constant even during un-certainties which means that there is no substantial reduction in the power drawn by the critical load. Now in order to save power or to release the battery and the renewable generator during uncertainties in the power generation the power drawn by the non-critical loads is suppressed to considerable extent which can be inferred from Fig. 9.

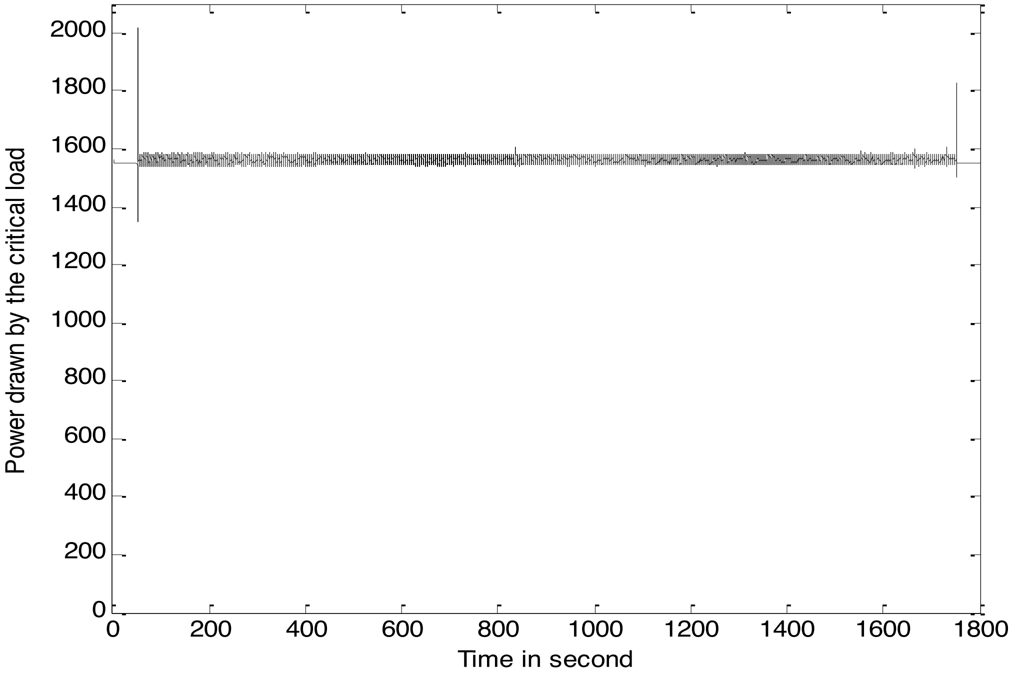

Fig. 8 Average value Power drawn by the Critical load

Fig. 9 shows the power drawn by the non-critical load where it can be noticed that during generation sufficiency i.e. up to 50th second and after 1750th second the power drawn by the non-critical load is around 1760 watt and during deficits in power generation the power drawn by the non-critical load is around 1200 watt which is a straight dip of around 560 watt. This means that instead of curtailing the non-critical load completely by using smart techniques like the Electric spring substantial amount of power saving can be achieved.

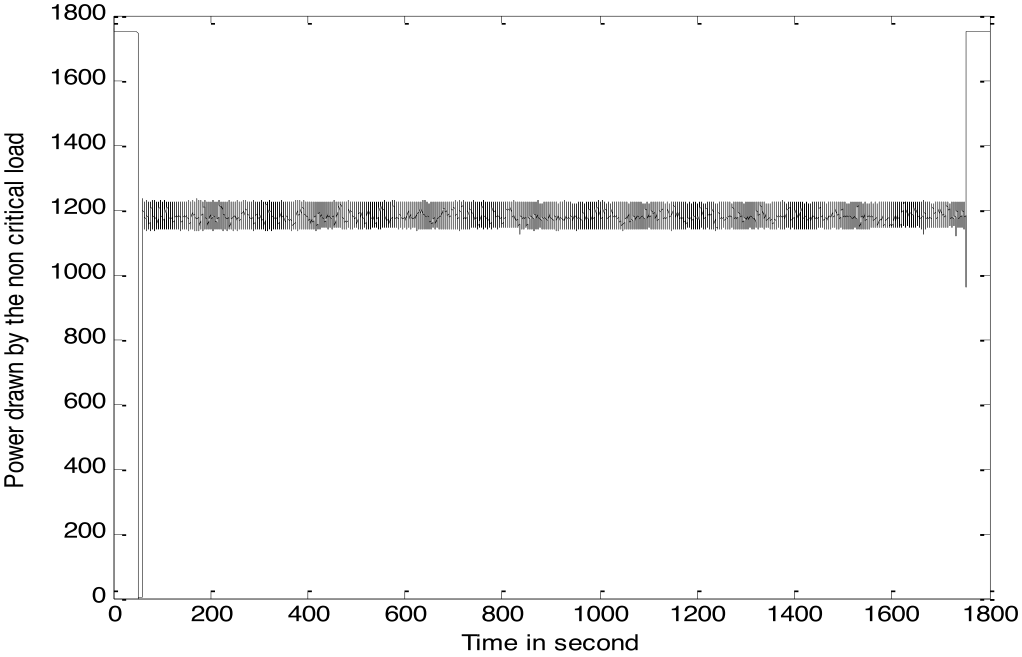

Fig. 9 Average value of the power drawn by the non-critical load

Making a comparative study of the power drawn by the critical and non-critical loads with and without D.C Electric spring it is very encouraging to use them in smart grid environments and are as follows

Table.2 Different parameters of the grid elements without the action of D.C Electric spring

| S. No. | Average Power drawn from the source without D.C spring | Average current drawn from the source without D.C spring | Average current drawn from the battery without D.C spring | Average Power drawn from the battery without D.C spring |
|---|---|---|---|---|
| 1. | 2.0091 kW | 8.2340 A | 6.8611 A | 1.622 kW |

Table.2 shows the different parameters which are observed during the course of simulation for a time of 1800 second where the Average values of power drawn from source and battery, current drawn from the source and battery are projected. Table 2 gives information of different electrical parameters when the D.C Electric spring is not in action i.e. the micro grid system runs on battery support during un-certainties in power generation and the voltage applied to both the critical and non-critical loads is same i.e. 220 volt which means that there is no power saving by the non-critical load.

Table.3 Different parameters of the grid elements with the action of D.C Electric spring

| S. No. | Average Power drawn from the source with D.C spring | Average current drawn from the source with D.C spring | Average current drawn from the battery with D.C spring | Average Power drawn from the battery with D.C spring |
|---|---|---|---|---|
| 1. | 1.7904 kW | 7.3093 A | 6.3598 A | 1.5064 kW |

Table .3 gives information about different electrical parameters when D.C Electric spring is pressed into action i.e. the noncritical load works at 180 volt during generation un-certainties. So by comparing the corresponding values in Table.2 & Table.3 it can be noticed that the difference in power drawn from the source is around 218 watt and from the battery is around 115 watt and in the same way there is a difference in the Average current drawn for both the cases. It can be estimated that due to the action of E.S (D.C) the power drawn from the supply system (power source and battery) is reduced by 12 % i.e. from 3.6 kW without the action of spring and to 3.29 kW with the action of spring.

It is interesting to notice from the above comparison that for considered fluctuations in the source voltage not only the battery but also the source is relieved to a certain extent because of the action of spring. If the objective is to reduce the battery storage requirement it can be compared and estimated that there is 8 % reduction in the power drawn from the battery which means that battery storage requirement gets lesser. Apart from the power drawn from the battery if the Average current drawn from the battery is considered there is a reduction of around 0.5 Ampere of current drawn which clearly states that by using D.C Electric springs there can be reduction in the Ah capacity of the battery also which will be very helpful in saving capital as well as maintenance costs incurred for the battery storage.

## 4. Conclusion

From the proposed work it can be established that usage of D.C Electric springs in the existing D.C micro grid systems can largely relieve the battery and the renewable generator during un-certainties in the power generation by the source. For the considered fluctuation pattern of the output voltage there is a saving of 8 % in the power drawn from the battery and also by looking at the saving in the power drawn from the supply system during generation uncertainties it can be seen that there is 12 % reduction in the power drawn which means that using D.C Electric Spring not only the battery storage requirement gets lesser but also the power drawn from the supply system as well as the source gets reduced which means that usage of D.C Electric spring in the micro grid system will realize both the objectives. It can be noted that for a different pattern of output voltage of the source the reduction in power drawn will be different. The future scope of this work can be on developing suitable devices or equipment which can operate at higher voltage tolerance and such devices will be useful if the micro grid structure is weakly regulated. Further this type of technologies can be used in D.C micro grids to reduce the energy storage requirements in future.

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